Trade, Production And Use Of Electrical And Electronic Equipment, In The Context Of The Circular Economy

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ABSTRACT

At the level of the European Union, the implementation of circular economy principles is in early stages, despite the involvement of political decision-makers through the adoption, since 2015, of a set of dedicated policies and different national government strategies. The waste of electrical and electronic equipment (WEEE) recovery activity is of greater importance for countries that apply the principles of the circular economy, being a form of resource saving.

The research focuses on analysing the main drivers of sustaining the circular economy of the electrical and electronic equipment (EEE) sector, pointing out the importance of resources efficient use and waste recovery. Our panel dataset consider the period 2008-2020, for EU-27 countries. The analysis carried out highlights the importance of the EEE sector in implementing the principles of the circular economy by promoting products with medium and high level of technology and saving resources for households.

Keywords: *Circular economy, Sustainable Development, Waste of electrical and electronic equipment*

JEL Classification: *D16, Q01, Q53, O13, O14*

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INTRODUCTION

The concept of „circular economy" represents one of the main points of interest for decision-makers at the international level, representing a way by which the objectives of sustainable development related to the reduction of the massive consumption of natural resources can be achieved, but through which economic benefits can be obtained by companies (Lieder and Rashid, 2016; Kirchherr et al., 2018; Rizos V., Bryhn J, 2022).

Global economic development is closely related to the consumption of electrical and electronic equipment (EEE) that have become an essential aspect of our everyday life. A large part of the world's population now enjoys high standards of living based on the availability and widespread use of these equipment.

Although the advantages for users are major, the ways of manufacturing, of using and recycling e-waste are contrary to the principles of sustainable development. Due to the reduced logistical facilities for the collection and recycling of waste of electrical and electronic equipment (WEEE), the impact on the environment is worrying through the consumption of resources, the toxic substances released during the recycling procedures, the emissions of greenhouse gases (Juchneski, 2022).

1. REVIEW OF THE SCIENTIFIC LITERATURE

At the level of the European Union, the implementation of circular economy principles is in early stages, despite the involvement of political decision-makers through the adoption, since 2015, of a set of dedicated policies and different national government strategies (Salvatori et al., 2019).

The phenomenon of urbanisation and the increasing mobility of the population, higher levels of income but also the continuous process of industrialization, led to an increase in the amount of electrical and electronic equipment in the global economy. On average, the total weight of global electrical equipment consumption (excluding photovoltaic panels) increases by 2.5 million metric tons annually (Forti et al., 2020). An inadequate management of electronic waste affects both the environment and human health (Juchneski, N.; Antunes, A. 2022).

In order to improve the performance of electrical and electronic products, the profile industry is growing, the products put on the market being modified and improved (Mori de Oliveira et al., 2022). The COVID19 pandemic has further affected the sales of these products, as many people have

been working or learning from their personal homes. In addition, users are mainly interested in devices that incorporate the latest technology, which are more expensive but provide an improved user experience (Schumacher et al., 2019; Scarsella, 2022).

At EU level the growth of the WEEE (also known as e-waste) is very fast, with current annual growth rates of 2%. According to the EU's Circular Economy Plan, it is estimated that around 40% of e-waste is recycled within the EU (EC, 2021a). The EU Circular Economy Action Plan envisages the promotion and launch of initiatives applied to the entire product life cycle, from production to consumption, repair and processing, waste and raw material management.

The increase in demand for electrical and electronic equipment is accompanied by problems such as the amount of energy used for production but also for their use, water consumption and the production of toxic waste water from the stage of exploitation by the user or the use of finished materials in the EEE composition. For the European Union, most of these materials have a critical degree of availability, such as precious metals or rare metals (Reuter et al., 2013; Weetman et al., 2016)

Electrical and electronic equipment is made of many components, which can be manufactured in different countries, exported to another country to be processed or assembled, and then delivered to customers around the world. The pattern of international trade transactions thus becomes very complex as the demand increases. The largest producers and exporters of electrical and electronic equipment are China, US, South Korea, Taiwan, Japan and Germany (ITC, 2021a), while US, Japan, China and Germany were the main consumer markets in 2021 (ITC, 2021b).

The European Union treaties analyzeraw materials with maximum priority, with a special monitoring system in place. The EU updates its list of critical raw materials every three years, based on demand, supply and shortage estimates for materials considered critical (EC, 2021b). The 2020 EU list of critical raw materials contains 30 materials, compared to 14 materials in 2011, 20 materials in 2014 and 27 materials in 2017. Supply of critical raw materials is concentrated in countries such as China, which supplies 98% of rare metals, Turkey covering 98% of the EU's borate needs, South Africa providing 71% of the EU's platinum needs. (EC, 2021b).

The main problem raised by the use of electrical and electronic equipment is the short time of use, as they are not designed and manufactured to serve the users in the long term. Thus, electrical and electronic equipment available at a given time on the market are obsolete faster and the possibilities of repair are reduced (Mori de Oliveira et al., 2022; Bachér et al., 2020)

From a user perspective, based on European Commission studies, two out of three Europeans would like to use their digital devices for longer, provided that performance is not significantly affected (Special Euro Barometer, 2020). To address these challenges, as part of the European Green Deal, the European Commission presented in March 2020 a new circular economy action plan (EC, 2021c-f), which addresses shortcomings in terms of product durability, the presence of hazardous substances and harmful, recycled content, repairability, access to spare parts, e-waste reduction, collection, reuse and recycling. In the resolution of February 10, 2021 on the New Circular Economy Action Plan, the European Parliament supported the European Commission's Initiative and additionally requested the integration of aspects related to the early obsolescence of products caused by software changes as well as the harmonisation and improvement of the waste recycling infrastructure electrical and electronic equipment in the EU to guarantee efficient material recovery and environmental protection.

At EU level, the share of EEE production in the whole manufacturing industry was 3.1% in 2019 (the last year for which detailed data is available at Eurostat). In Romania, the EEE production counted for 2.6%, with 0.2 pp greater than previous year. This explains the concerns raised at national level about the WEEE treatment and recovery.

WEEE, if not treated properly, is harmful to the environment, as it often containscomplex combinations of highly toxic substances. Burning untreated WEEE can release hazardous chemicals, such as dioxins (Perkins et al, 2014). The use of certain metals in such equipment, such as lead and mercury, has been restricted in the EU since 2003, but those may still be present in older products (Directive 2011/65/EU).

Proper treatment of e-waste can yield significant economic benefits and reducedemand for raw materials. For instance, 1 tonne of smartphones contains about 100 times more gold than 1 tonne of gold ore (World Economic Forum, 2019). E-waste may also contain other important metals such as copper, nickel, indium or palladium (Intosai, 2016). Recycling e-waste also contributes to climate change mitigation, given that it avoids emissions of greenhouse gases resulting from the production of new materials, in particular metals (Golsteijn et al, 2017).

The WEEE Directive establishes a range of collection targets for WEEE, first phase from 2006 at least 4 kg/per inhabitant per year collected from private households, second phase from 2016 electronic equipment placed on the market in the 3 preceding years in the member state for 10 states and the third phase 65% of average weight of electrical and electronic equipment placed on the market in the 3 preceding years in the member state

or 85% of WEEE generatedon the territory of the Member States and also sets several recovery targets with minimum targets for preparing for reuse and for recycling. Recovery relates to recycling and extraction of metals and metal compounds, as well as incineration to generate energy (Directive 2008/98/EC).

The EU finances research and capacity building in the area of e-waste, having provided close to €100 million through Horizon 2020 (CORDIS European Commission, 2022), and over €8 million through the LIFE Programme (Life Public Database European Commission, 2021). The EU budget also provides some funding for general waste infrastructure through the Cohesion Fund and the European Regional Development Fund, but the data published by the Commission do not make it possible to determine whether a share of this funding goes towards infrastructure that is relevant to e-waste (Cohesion open data platform 2014-2020, 2022).

Global statistics on e-waste show higher rates of e-waste collection and treatment in the EU than in most parts of the world. Data from the Global E-Waste Statistics Partnership identify Europe (including both EU and non-EU countries) as the continent with the highest generation of e-waste per capita, but also as the part of the world with the highest WEEE collection and recycling rates. Europe generates a per capita amount of e-waste comparable to the Americas and Oceania, but has a collection and recycling rate that is over four times (European Court of Auditors, 2021).

EU Member States tend to outperform most non-EU countries in the collection of e-waste, including developed countries such as the United States and Japan.

2. RESEARCH METHODOLOGY

The research focuses on analysing the main drivers of sustaining the circular economy of the electrical and electronic equipment (EEE) sector. Our panel dataset contains data for the period 2008-2020, for all the EU-27 countries, except Croatia. We have excluded Croatia because its information for almost all the indicators was unavailable for the given period.

The following data sources were used:

- Eurostat database, for the following indicators: *GDP per capita, Import/Export waste of EEE, Import/Export of EEE, Waste of EEE (WEEE) collected from households, WEEE treatment, WEEE Recovery, Products (EEE) put on market, Consumption of EEE in households,*

- Online database for the Sustainable Development Report 2022, for Sustainable Development Indices (*Spillover Index, General Index*).

- The interactive database of the Global Innovation Index 2021, for *Research and Development Index.*

According to the data sources mentioned above, the indicators used for the purpose of this paper have the following content:

GDP per capita is calculated as the ratio of GDP to the average population in a specific year. (Eurostat, 2022).

Data on Waste electrical and electronic equipment (WEEE) is collected on the basis of Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE). The purpose of the collected data is to monitor compliance of countries with the quantitative targets for collection, preparing for re-use and recycling, and recovery of WEEE that are set out in Article 7 (collection rate) and Article 11 and Annex V (recovery targets). This decision is applicable on the following categories: EEE put on the market, WEEE generated, WEEE collected (from private households; from users other than private households; total), WEEE collection rate, WEEE preparing for re-use, WEEE recycling, WEEE preparing for re-use and recycling, WEEE recovery, WEEE treated.

GDP per capita, WEEE collected from households, WEEE treatment, WEEE Recovery, EEE put on market, Consumption of EEE in households, selected for NACE Rev2 codes: 2620 - Manufacture of computers and peripheral equipment, 2630 - Manufacture of communication equipment, 2640 - Manufacture of consumer electronics, 2740 - Manufacture of electric lighting equipment, 2751 - Manufacture of electric domestic appliances, 2823 - Manufacture of office machinery and equipment (except computers and peripheral equipment). These codes correspond to EEE for private households classified in Annex III and Annex IV in Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE).

Import/Export WEEE, identified using the Combined Nomenclature code 8548 "Waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators; electrical parts of machinery or apparatus, not specified or included elsewhere chapter 85"

Import/Export of EEE, identified using the Combined Nomenclature code 85 "Electrical machinery and equipment and parts thereof; sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles" except CN code 8548 "Waste and scrap of primary cells, primary batteries and electric accumulators; spent primary cells, spent primary batteries and spent electric accumulators; electrical parts of machinery or apparatus, not specified or included elsewhere chapter 85"

In a highly interdependent world, countries' actions can have positive or negative effects on other countries' ability to achieve the Sustainable Development Goals (SDGs). *The Spillover Index* assesses such spillovers along three dimensions: environmental & social impacts embodied into trade, economy & finance, and security. A higher score means that a country causes more positive and fewer negative spillover effects. Environmental and social impacts embodied into trade (Sustainable Development Solutions Network, 2022).

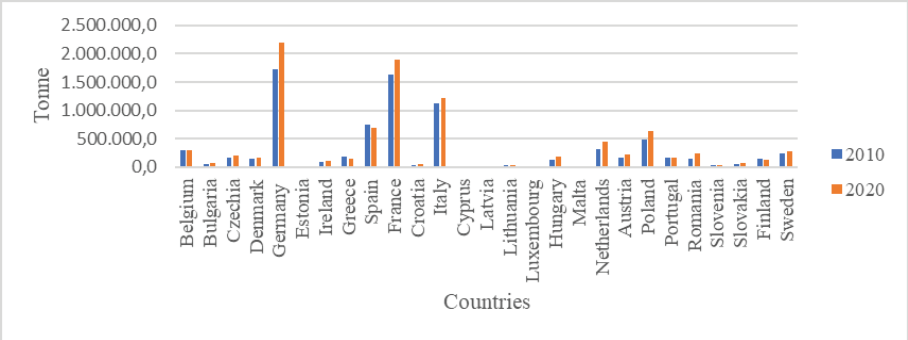
At the EU level, the Import of Waste recorded higher values in 2020 compared to 2010 in Germany, Netherlands, Poland, Belgium, Hungary, France and constant values in Latvia, Lithuania, Malta, Luxembourg, Cyprus, Greece and Croatia.

Waste Export values are directly proportional to waste import values, with Germany, the Netherlands, France, Belgium and Poland seeing increases in waste export values in 2020 compared to 2010.

The values of Import and Export of Waste are in an interdependent relationship with the products put on the market, so Germany, France, Italy, Spain, Poland, the Netherlands recorded increases in the products put on the market in 2020 compared to 2010.

Products put on the market in EU

Figure 1



Source: Authors own processing based on Eurostat Database

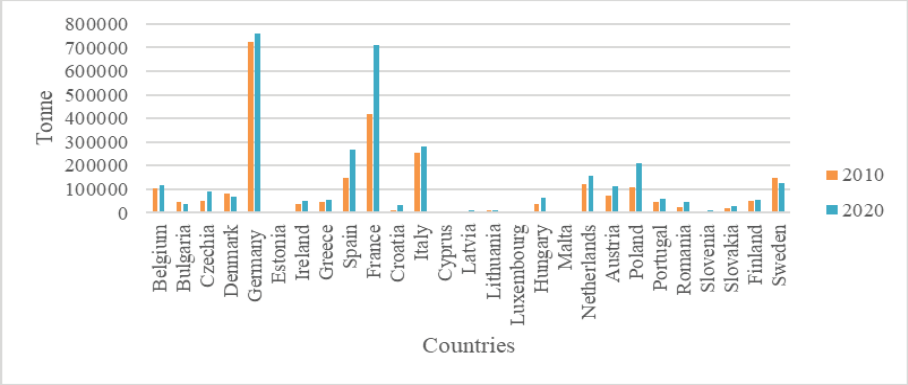
The trend regarding the consumption of EE in households has remained constant in the period 2010-2020, the countries that have registered gradual increases in the analyzed period are: Bulgaria, Romania, Croatia, Lithuania and Greece.

EE waste collected from households saw slight increases in 2020 compared to 2010 in Germany, Italy and Poland, and a significant increase in

France, which is due to a national program through which citizens receive a sum of money to repair their electronics and household appliances, a unique program in Europe aimed at extending the life of equipment and reducing waste (Gouvernement du France, 2022).

Waste of EE collected from households in EU

Figure 2



Source: Authors own processing based on Eurostat Database

Waste treatment (the activities required to ensure that waste has the least possible impact on the environment and in many countries various forms of waste treatment are required by law) has seen a significant increase as a result of government measures in France (see the Figure 2) and a decrease in these measures in Italy and Denmark.

Research Development Index recorded increases in 2020 compared to 2010 in Germany, Netherlands, Italy, Ireland, Hungary, Greece and recorded decreases in Finland, Estonia, Czech Republic, Romania, Croatia.

At the EU level the Spillover Index and General Index registered increases in all EU Member States in 2020 compared to 2010.

Effective waste management in many EU states is due to the application of EU legislation in the community space, the purpose of European waste legislation is to encourage waste prevention, to specify requirements on the reuse and recycling rate for certain waste streams, to minimize disposal in landfills compliant and eliminate disposal in non-compliant landfills. The benefits of the Circular Economy Action Plan, one of the main components of the European Green Deal, cannot be fully exploited as long as illegal dumping practices persist in another countries.

In order to analyse the level of correlation between the previously defined indicators, we have constructed the following research hypotheses:

H1. The economic development of the EEE sector is a factor that drives products' competitiveness.

H2. Is the level of economic development of the countries a cause or an effect for a circular economy defined by export and import?

H3. The import of EEE waste is correlated with the products put on market, collected, treated and recovered.

H4. The level for accessing the sustainable development goals is correlated with the level of R&D sector and EEE products put on the market. At a first stage, we have computed the correlation matrix, using the Person product--moment method, implemented in R.

We have used panel regression models and the software used for all the analysis is R (R Core Team, 2021). In table no. 1 the dependent and independent variables used in the econometric models were listed.

Variables used in the analysis

Table no. 1

Dependent variables	Independent variables
1. Spillover Index 2. General Index 3. GDP per capita in current prices (euro) 4. Import waste of EE	1. Import waste of EE
	2. Export waste of EE
	3. Products put on the market (tonne)
	4. Consumption of EE in households
	5. Waste of EE collected from households (tonne)
	6. Waste treatment
	7. Waste recovery (tonne)
	8. Research.Development.Index

Source: Authors' selection from databases of Eurostat, SDG Index.org, Global Innovation Index

3. Short overview of electric and electronic equipment sector in European UnionThe EEE sector is naturally integrating in the principles of sustainable development and could be defined by it. Developing and implementing effective and ambitious environmental and climate strategies and policies aimed at achieving net-zero greenhouse gas emissions by 2050 and commensurate medium-term targets in line with this pathway. Achieving these objectives requires the implementation of transparent, objective-based policies to ensure the long-term conservation of biodiversity and its sustainable use.

Waste management is included in the list of fundamental principles of accession for the OECD committees, of the candidate countries, among which

are also three member countries of the European Union, respectively Bulgaria, Croatia and Romania (Council at Ministerial Level OECD, June 2022).

The OECD principles with respect to sustainable management of resources, implementing integrated life-cycle-oriented approaches to waste and materials (including plastics) management and establishing framework conditions for a more resource-efficient and circular economy. Ensuring that generation of waste, including hazardous waste, is reduced, export of waste for final disposal is minimised, and that waste is managed in an environmentally sound manner. Controlling exports and imports of hazardous waste while allowing trade in waste as end-of-life materials and products destined for economically efficient and environmentally sound recovery operations within the OECD area.

The European average was made for general index, spillover index, products put on market, waste collected, waste treatment and recovery.

The correlation analysis revealed significant relationships between most of the factors, except consumption (table no. 2). Consequently, they were successively introduced in the models.

Correlation matrix

Table no. 2

Variable	Import waste of EEE	Export waste of EEE	Products put on the market	Consumption of EEE in households	Waste of EEE collected from households	Waste treatment	Recovery
Import waste of EEE	1						
Export waste of EEE	0.840494	1					
Products put on the market	0.746248	0.786959	1				
Consumption of EEE in households	0.012771	-0.016505	-0.057122	1			
Waste of EEE collected from households	0.776765	0.811679	0.963293	-0.044954	1		
Waste treatment	0.729430	0.743071	0.945551	-0.076383	0.941663	1	
Recovery	0.782863	0.795416	0.963819	-0.064516	0.976531	0.985726	1
Research. Development. Index	0.402573	0.473240	0.421908	-0.352802	0.486145	0.434084	0.463825

Source: Authors' calculation performed in R

The equations corresponding to the models are the following:

Model 1:

Spillover.Index ~ Import.Waste.euro + Export.Waste.euro + Products.put.on.the.market.tonne + Consumption.of.electric.equipment.in.household (1)

Model 2:

GDP.per.capita.current.prices.euro ~ Import.Waste.euro + Export.Waste.euro + Products.put.on.the.market.tonne + Consumption.of.electric.equipment.in.household (2)

Model 3:

Import.Waste.euro ~ Products.put.on.the.market.tonne + Waste.collected.from.households.tonne+ Waste.treatment.tonne + Recovery.tonne (3)

Model 4a:

General.Index ~ Products.put.on.the.market.tonne + Research.Development.Index (4)

Model 4b:

Spillover.Index ~ Products.put.on.the.market.tonne + Research.Development.Index (5)

3. RESULTS AND INTERPRETATION

The econometric model used for testing the hypotheses is a panel regression (table no.3). In all five models the country has been considered as factor.

Panel regression results

Table no. 3

Models	Model 1		Model 2		Model 3		Model 4a		Model 4b	
Independent Variables	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
Import waste of EE	8.893e-09	0.135	2.235e-05	0.0101 *						
Export waste of EE	-6.084e-09	0.377	3.940e-06	0.6942						
Products put on the market	4.674e-06	0.075 .	4.603e-03	0.2276	2.755e+02	< 2e-16 ***	4.393e-06	8.72e-06 ***	7.089e-06	0.00107 **
Consumption of EE in households	-9.611e-01	2.76e-07 ***	-1.357e+03	5.93e-07 ***						
Waste of EE collected from households					-7.348e+01	0.411310				
Waste treatment					6.575e+01	0.379775				
Recovery					6.133e+01	0.679531				
Research. Development. Index							4.450e-02	0.0129 *	7.590e-02	0.05439 .

*Notes: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

Source: Authors' calculation performed in R

The first hypothesis is confirmed by model 1. The Spillover Index is highly correlated with the consumption of electric equipment in households for all the member states. The economic development of the EEE sector is a factor that drives to products' competitiveness, as these products are included in the category of medium and high-tech technological intensity. The negative coefficient of the export shows clearly the lack of reusing waste: a country is exporting waste and does not use it for production. Reusing EEE waste could be associated as a valuable asset because it ensures production from the reuse of waste and consequently it saves resources.

Compared to the first hypothesis, the second one reveals that in an analysis specific to an economic sector of a national economy, it is better to use as a dependent variable complex indices such as Spillover Index, instead of the classical GDP per capita. The share of the EEE sector in the economy is relatively small, therefore it is more important to analyse the correlation

not by the effect on the economic development, but by specific and complex indicators. In conclusion, model 1 is more relevant than model 2.

According to the third model, the import of EEE waste is in correlation with the products put on market for: Austria (-2.576e+07), Denmark (-3.852e+07), Finland (-2.903e+07), France (-4.146e+08), Germany (-2.264e+08), Greece (-4.105e+07), Hungary (3.783e+07), Ireland (-2.205e+07), Italy (-2.629e+08), Netherlands (2.384e+07), Poland (-8.814e+07), Portugal (-2.503e+07), Romania (-3.318e+07), Slovenia (1.639e+07), Spain(-1.234e+08), Sweden (-3.311e+07). The import of EEE leads to increasing production of EEE in countries in which there is a policy of valuing through recovery the products resulted from waste processing. Depending on some parameters such as share of the sector in economy, technological level and household consumption, every country has differentiated policies regarding the EEE waste. If households are reusing EEE, the policy addressed to waste is different. If the households are wasting the EEE, the policies will focus on recovering.

Last two models, 4a and 4b, are testing whether the level of complying with sustainable development goals is related with the level of R&D development and with the products put on market. Because of the regionalization, the business environment ensures a convergence of economic restructuring and technological progress. Therefore we will consider two country groups, ie “old” and “new” EU member states (ie before and after 2004). For the old member states (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Portugal, Spain and Sweden), the correlation is higher between general Index and products put on the market and R&D Index, with coefficients between 6.902e+01 (for France) and 8.193e+01 (for Finland). The correlation with the Spillover Index is lower, with coefficients between 2.034e+01 (for Germany) and 3.575e+01 (for Luxembourg). Nevertheless, the significance is maximum for all the member states in both models 4a and 4b. However the influence of R&D Index and products put on market are higher on the General Index compared with Spillover Index.

CONCLUSIONS

The analysis carried out revealed the importance of the EEE sector for the national economy, taking into account the opportunities for development of economic activity and job creation in a sector characterised by medium and high level of technology. The WEEE recovery activity is of greater importance for countries that apply the principles of the circular economy, being a form of

resource saving. From this perspective, at the level of EU member states there are different political approaches. Countries with poor performance in WEEE recovery need to adjust their policies by adopting international good practices and adapting to their own economies as well as by developing/educating consumption behaviour (both private industrial and household users). By these means, the consumption of equipment/products at higher technological levels is stimulated; in the same time it is ensured the appropriate use of equipment in the context of an increased assortment diversity in private households.

A worrying aspect is lack of proper recycling and reuse facilities for EEE waste. Some countries prefer to export EEE waste produced in their own economy to other countries instead of sustaining the development of a specific infrastructure for reintegration of recovered materials into the production process. For EEE waste-importing countries, these products can be transformed into valuable assets by increasing the production of goods obtained by reusing the waste and, consequently, achieving savings in basic resources.

The import of WEEE leads to an increase in the production of EEE in countries where there is a policy of valorization of products resulting from waste processing. The waste recovery is closely related to the trade balance (export-import of WEEE) as well as to the behaviour (responsible or not) of consumers. If private households choose to repair for reuse of EEE instead of purchasing new equipment, the policy in the field will focus on increasing the products life by offering specialised repair services and ensuring maintenance. Otherwise, if households adopt a behaviour characterised by EEE waste, the recovery policy will be stronger and facilities might be created to process and relaunch the materials recovered from WEEE into production process.

In order to be in line with circular economy principles, countries can adopt development policies by changing the consumption behaviour of users. There is a mutual influence between the behaviour of companies, on the one hand, oriented towards increasing the assortment, technological level and economic efficiency under comparable conditions of use values, and the behaviour of household users, on the other hand, which is influenced by the companies' offer. When the final customer is no longer satisfied with the offer of companies on the national market, he will turn to imported goods. Therefore, the phenomenon of selectivity in purchases takes place simultaneously with assortment diversification based on complementarity and efficiency in the use of EEE. The adoption of the principles of the circular economy may be delayed as the consumption behaviour, mainly of household consumers, is more difficult to change over time.

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